XX. *On the Evolution of Nitrogen during the growth of Plants, and the Sources from whence they derive that element.* *By* Robert Rigg. *Communicated by the Rev.* J. B. Reade, *M.A. F.R.S.*

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In this communication I shall have the honour of submitting to the Royal Society a series of experiments, which not only confirm the principles I have already laid down in the investigations of the influence of nitrogen on the growth of plants, but also enable us to trace this important element to its source.

By what mysterious process of natural chemistry the living principle of the plant obtains this product, we must be content to remain ignorant; but to what extent a supply can be procured from the compounds upon which its agency is directed, is within the compass of legitimate experimental research.

With respect to the entire volume of nitrogen connected with the process of vegetation, it will be observed that my former Tables show that the quantity appropriated by the plant varies from $\frac{1}{1000}$ to $\frac{1}{5}$ of their weight of carbon; and the important experiments of Dr. Daubeny, Saussure, Sir Humphry Davy and others, have abundantly established the fact that there is a considerable evolution of nitrogen during the growth of plants. Experiments, however, upon the quantity of nitrogen evolved are so beset with difficulties, that our best efforts in this department of vegetable physiology have not enabled us to speak with certainty as to the absolute or relative quantities of the gases which are given off during the healthy action of the functions of vegetable life. And in corroboration of this remark it is only necessary to state, that the natural course of vegetation is unavoidably interrupted, by the necessity we are under of excluding plants from the free action of the external atmosphere, when we attempt to collect the gases they give off.

Sir Humphry Davy made his experiments under as favourable circumstances as the nature of the case will admit of; and he found that when the oxygen decreased in quantity about two per cent. the nitrogen increased four per cent., and that when the oxygen increased about thirty-five per cent. the nitrogen increased about seven per cent. Some of my own experiments have been conducted on the principle adopted by Sir Humphry Davy. I have also introduced whole branches of trees, as well as stems and leaves of more tender plants, under water, without removing them from the parent stock, and collected their gaseous products in inverted glass vessels. Upon examining these products, I find, that the gaseous volumes are perceptibly affected by the brightness of the sun's rays, though their variation appears to be subject to no

fixed law. At the same time, however, it is certain that nitrogen, whether appropriated or evolved, is apparently the most uniform, while oxygen assumes the character of a most fluctuating and passive agent.

Hence, then, if plants, taken as a whole, contain from three to four per cent. of their weight of nitrogen, and if to this we add the indefinite quantity, so far as we can comprehend, which is evolved during their growth, the question naturally arises, From whence do plants draw this part of their substance, as well as the volume of nitrogen which they furnish to the atmosphere? a question of the greatest importance in the practical application of the subject, and one not wanting in interest as a part of the inquiry into the chemical changes which occur during the growth of plants.

The quantity of animal and vegetable matter which forms a part of all soils suitable for the growth of plants, invariably containing nitrogen, furnishes us at once with one source from whence they may derive a part, if not the whole, of this element, which is either found in their constitution, or given off to the atmosphere during their growth. Hence an accurate examination of these soils at different periods might enable us to determine the question as to whether or not the earth supplied the whole of the nitrogen which is employed in vegetable economy. But from the many difficulties consequent upon accurately experimenting upon soils previous to and after the production of any plants, and also the examination of the plants so produced, we are not able by this mode of proceeding to obtain results in any degree satisfactory.

In order to free myself from all doubt upon this point, and to ascertain whether *the atmosphere* did or did not furnish any part, and if any what proportion, of the nitrogen which enters into the constitution of plants, I had recourse to the ultimate analysis of seeds and young seedling plants.

Some seeds I steeped in distilled water, and some in filtered Thames river water. When they had absorbed a sufficient quantity of water to favour the first impulse of germination, I spread them on glass or china plates, and kept them at temperatures favourable to germination and vegetation, in a room where the only source of nitrogen would be that which was supplied by the seed and the atmosphere. The quantity of dry seed experimented upon varied from thirty to one thousand grains, which were accurately weighed. These I allowed to germinate and grow, keeping them regularly supplied with the respective kinds of water only; and that nothing might be lost by the water carrying off any of the soluble parts of the different seeds, that water which was employed in steeping each kind of seed at the commencement was afterwards used in watering the same.

Some of the experiments I favoured so as to have them germinating and growing quickly, and others slowly. Some of them were terminated at one stage of their growth, and some at another; and some of them were allowed to vegetate as long as the seeds appeared to afford them nourishment. At the end of each experiment the whole mass was enveloped in very thin paper, and dried at a temperature varying from 100° to 110° FAHR., powdered, and afterwards allowed to acquire the hygrometric state

of the atmosphere. They were accurately weighed in this condition, a portion of each part, or of the entire mass, subjected to ultimate analysis, and calculation made for the whole. Thus I was enabled to discover an increase or decrease of any of the elements in any experiment so conducted, wherein the seed itself, the water, and the atmosphere furnished whatever was required for vegetation. The experiments which have reference to this part of the subject are found in Table X.

We are led by these experiments to the inference, that, independent of that indefinite quantity of nitrogen which is given off to the atmosphere during vegetation, there is an increase of this element in plants when compared with its quantity in the seeds; and in this case the seeds form the only source from whence they could derive it, with the exception of the atmosphere and any little which might have combined with the water used on the occasion.

It would be at variance with my mode of research, which is purely experimental, to make any observations upon the quantity of nitrogen which is probably furnished by the atmosphere during the germination of seeds and the full growth and developement of plants. The experiments before us dispose us to infer that it differs with the temperature at which the plants are exposed, and with exposure as regards sunshine and the shade. Thus we have in the germination and vegetation of barley, for instance, the quantity of nitrogen in the grain germinated under very favourable circumstances for the process, increasing to an extent equal to thirty-eight per cent. upon the original quantity contained in the seed: when the same kind of barley was kept under unfavourable circumstances for vegetation, and allowed to grow until the principal part of the farina was exhausted, the increase in the quantity of nitrogen was only eighteen per cent. When the same grain was allowed to vegetate in the sun's rays until about two-thirds of the flour contained in the seed had disappeared, the increase in the quantity of nitrogen was thirty per cent.; and when the same plants were kept under the most favourable circumstances, and allowed to vegetate until the seeds appeared to be exhausted, the young plant during this time having the most healthy appearance, there was an increase upon the quantity of nitrogen contained in the seeds of *nearly fifty per cent.*

Seeds of cress during vegetation increased their quantity of nitrogen forty-one per cent. when the plants were kept under a temperature varying with shade and sunshine from 60° to 84°. The experiments upon the seeds of the turnip, an important plant in an agricultural point of view, (about one half of which germinated,) shows that the nitrogen which was derived from the atmosphere was more than that which was contained in the seed. In all these experiments we have the quickness of the growth of the young plants proportional to the quantity of nitrogen present when compared with 1000 parts of carbon in the same.

With these facts before us, we are enabled to account for plants not continuing to grow so well in pure oxygen gas as in atmospheric air; and by following up the inquiry in other departments, we see the wisdom of the all-wise Contriver in consti-

tuting an atmosphere with a decided preponderance of nitrogen and a much smaller proportion of oxygen.

Finding that plants under different circumstances of growth differ in the relative quantity of nitrogen which they contain, as well as in the other elements which enter into their constitution, I was desirous of obtaining information which would lead us to account for the well-known fact of plants increasing most in size during cloudy weather, and of grasses, for instance, which are shaded (as under hedges), increasing much in straw, but producing seed both small in quantity and inferior in quality.

By way of commencement in this part of the research, I made duplicate experiments with the same kind of seeds, steeped them in and supplied them with the same kind of water, and kept them under equal circumstances in every respect, except that of placing one of each in the sun's rays in the greenhouse, where the sun shone till three P.M., and the other in the same situation, excluded however from the sun's rays, but not from the light. Those in the shade increased in length much more than the others, were a little lighter in colour, and when weighed before they were exposed to the drying temperature, were also heavier, but when dried at 100° to 110° were considerably less in weight. The ultimate analyses of these experiments are found in Table XI., and the result of the experiments as regards nitrogen is, that those plants which weighed the heaviest before drying, and which had as it were moulded into shape the largest quantity of matter in the form of plants, contained, in the cress for instance, 147 parts of nitrogen for every 1000 parts of carbon; whereas those plants from seed of the same kind which grew in the sun's rays, and whose weight before drying and when freed from foreign water was nine per cent. lighter than the other, contained only 111 parts of nitrogen for 1000 of carbon;—and in addition I might make an observation which is in perfect harmony with all that has been noticed upon the influence of nitrogen on the growth of plants, viz. that whereas the cress arrived at its state of maturity, so far as the seed could furnish it with nourishment, in eighteen days, the rape had not exhausted all its seed in twenty-six days; and the proportionate quantity of nitrogen in those plants was, in cress in the sun's rays 111, in rape in the same situation 73; and in cress in the shade 147, and in rape 82, when compared with 1000 parts by weight of carbon in each.

In concluding this subject, upon which I have been as brief as its nature would admit of, not even entering at all upon the practical application thereof, the point of view wherein its real value consists, I beg to observe that, although nitrogen appears from these experiments to be a very powerful agent in the economy of plants, it is far from my intention to give it any undue importance. It is my object to draw attention to an element which, comparatively speaking, has escaped unnoticed, and to vindicate the necessity of a most scrupulous attention to those products which, though so minute in quantity as to be with difficulty detected in our balances, have nevertheless been wisely assigned to discharge the most important functions.

TABLE X.

		Carb.	Hydr.	Oxyg.	Nitr.	Resid.	Water. Total.	Nitr. for 1000 Carb.
Barley steeped in distilled water germinated quickly until the plumula of several seeds had passed through the grain.	The malt	35·14	....	1·51	1·73	1·15	44·67 = 84·2	49
	The rootlets and plumula	1·70	0·2	....	·18	·16	2·14 = 4·2	106
		36·84	0·2	1·51	1·91	1·31	46·58 = 88·4	
Barley in its original state		39·57	....	3·45	1·38	1·30	54·3 = 100	35
Increase		....	0·2	....	·53	·01		
Decrease		2·73	....	1·94	....	....	7·72 = 11·6	
Barley steeped in river water vegetated in the shade until the corn appeared to be exhausted.	The stems ..	7·98	·17	....	·61	·86	11·38 = 21·0	76
	The roots....	8·90	....	....	·72	1·00	13·37 = 23·99	81
	The husks ..	6·19	....	·25	·26	·53	7·27 = 14·5	24
	The liquid separated by drying	·04	·01	....	·02	....	= ·07	
		23·11	·18	·25	1·61	2·39	32·02 = 59·56	
Barley in its original state		39·57	....	3·45	1·38	1·30	54·3 = 100	35
Increase		....	·18	....	·23	1·09		
Decrease		16·46	....	3·2	....	....	22·28 = 40·46	
Barley steeped in distilled water, and vegetated until about two-thirds of the flour had disappeared; kept in the sun's rays.	Original state	39·57	....	3·45	1·38	1·30	54·3 = 100	35
	The vegetated mass	29·7	·5	....	1·80	1·3	44·3 = 77·6	60
	Increase	....	·5	....	·42	....	....	25
	Decrease	9·87	....	3·45	....	....	9·7 = 22·4	
Barley steeped in rain water grew until the stems were five and six inches long; kept in the sun's rays.	Original state	39·57	....	3·45	1·38	1·30	54·3 = 100	35
	Young plants	27·83	....	4·13	2·06	1·36	33·82 = 69·2	70
	Increase	....	....	·68	·68	·06	....	35
	Decrease	11·74	....	....	....	....	20·48 = 31·8	
Cress seed supplied with distilled water, and kept in the sun's rays.	The seed	46·77	1·53	....	3·27	4·8	43·63 = 100	71
	Young plants	37·59	·12	....	4·64	4·75	46·10 = 93·2	121
	Increase	....	....	....	1·37	....	2·47	50
	Decrease	9·18	1·41	....	....	0·05	6·8	
The same seed supplied with river water, and kept more in the shade.	The seed	46·77	1·53	....	3·27	4 8	43·63 = 100	71
	Young plants	33·9	·80	....	4·1	4.9	40·9 = 84·6	121
	Increase	....	....	....	·83	·1	....	50
	Decrease	12·85	·73	....	....	....	2·73 = 15·4	
Turnip seed supplied with river water, about half of which germinated.	The seed	55·48	3·45	....	3·55	3·1	34·42 = 100	65
	After vegetat.	40·70	1·82	....	4·48	4·48	32·62 = 84·5	109
	Increase	....	....	....	·93	1·38	....	44
	Decrease	4·78	1·63	....	....	....	1·8 = 15·5	
Rape seed, about two-fifths of which grew.	The seed	55·29	3·45	....	2·71	3·1	35·45 = 100	50
	After vegetat.	44·31	1·58	....	3·14	3·1	40·37 = 92·5	73
	Increase	....	....	....	·43	....	4·92	23
	Decrease ...	10·98	1·87	....	....	....	........7·5	

Table XI.

		Carb.	Hydr.	Oxyg.	Nitr.	Resid.	Water. Total.	Nitr. for 1000 Carb.
Cress seed supplied with river water, and kept in the sun's rays in the greenhouse.	The seed....	46·77	1·53	....	3·27	4·8	43·63 = 100	71
	Young plants.	40·03	·98	....	4·44	10·5	36·35 = 92·3	111
Increase		....	....	....	1·17	5·7	....	40
Decrease		6·74	·55	....	....	....	7·28 = 7·7	
The same kind of seeds, but kept in the shade.	The seeds....	46·77	1·53	....	3·27	4·8	43·63 = 100	71
	Young plants	30·08	·92	....	4·42	9·97	33·91 = 79·3	147
Increase		....	....	....	1·15	5·17	... .	76
Decrease		16·69	·61	....	....	....	9·72 = 20·7	
Rape seed supplied with river water, and kept in the sun's rays.	The seeds....	55·29	3·45	....	2·71	3·1	35·45 = 100	50
	Young plants	45·35	1·38	....	3·20	8·12	48·75 = 106·8	73
Increase		....	....	....	0·49	5·02	13·3 = 6·8	23
Decrease		9·94	2·07					
The same kind of seeds kept in the shade.	Seed........	55·29	3·45	....	2·71	3·1	35·45 = 100	50
	Young plants	39·34	1·90	....	3·19	7·52	38·65 = 90·6	82
Increase		....	....	....	·48	4·42	3·2 = ...	32
Decrease		15·95	1·55	....	....	....	.... 9·4	
Mustard seed steeped in river water; kept in the sun's rays.	Seed........	50·74	2·36	....	3·55	3·9	39·45 = 100	70
	Young plants	33·33	·88	....	3·98	5·0	37·51 = 80·7	119
Increase		....	....	....	·43	1·1	....	49
Decrease		17·41	1·48	....	....	....	1·94 = 19·3	
The same kind of seed kept in the shade.	Seed........	50·74	2·36	....	3·55	3·9	39·45 = 100	70
	Young plants	31·68	1·66	....	3·93	3·85	30·21 = 71·33	128
Increase		....	....	....	·38	....	....	58
Decrease		19·06	·70	....	....	·05	9·24 = 28·67	
The chemical constitution of the young plants mentioned in Table XI. when brought to 100 parts are	Cress in sun's rays	43·36	1·06	....	4·81	11·4	39·37 = 100	111
	Cress in the shade	37·92	1·16	....	5·57	12·6	42·75 = 100	147
	Rape in sun's rays	42·46	1·29	....	3·00	7·6	45·65 = 100	73
	Rape in the shade	43·39	2·1	....	3·55	8·3	42·66 = 100	82
	Mustard in the sun's rays	41·32	1·09	....	4·93	6·2	46·46 = 100	119
	Mustard in the shade	44·41	2·32	....	5·51	5·4	42·36 = 100	128

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